Available online at www.sciencedirect.com
SciVerse ScienceDirect
Energy Procedia 18 (2012) 966 – 973
Energy Procedia

Superficial evaporation in forced convection of porous medium in transitory laminates regime « Application on mint leaves drying »

Touati Boumediene[a*], Lips Bernard[b], Benyoucef Boumediene[c] , and Virgone Joseph[b]

[a]Energy Laboratory in Dry lands (ENERGARID) University of Bechar, Bechar, Algeria,

[b]Center of Thermal of Lyon (CETHIL), INSA of Lyon, Lyon, France,

[c] Research Unit of Materials and Renewable Energy (URMER) Abu Bakr Belkaid University, Tlemcen, Algeria

Abstract

In the present work, the authors suggest a bidimensional transitory numerical model in a laminar regime and a forced convection of coupled transfers of heat and mass during mint leaves drying.
The modelization is based on the resolution of transfer equations of the air within the interface and those of Luikov's theory in porous environment. The method used in the resolution is that known as the non finite volumes. This method requires the code of calculation developed by Patankar and based on algorithm SIMPLER. The Resolution of the transfer equations permitted us to determine the distributions of the temperature and the humidity within the two environments air mint leaves.

Keywords: Bidimensional transitory numerical model, laminar regime and a forced convection, transfers of heat and mass, modelization, finite volumes, mint leaves.

1. Introduction

Water evaporation is a classical phenomenon which we meet very often in many natural and industrial processes.
Many works **[1]**, **[2]**, **[3]**, **[4]** and **[5]** have benn made in the field of drying in order to master and contribute in its development.

* Corresponding author. Tel.: (00213) 558 398 061; fax: (00213) 49.81.90.24.
e-mail address:btouatidz@yahoo.fr

 doi:10.1016/j.egypro.2012.05.111

The theoretical study, deals with numerical modelization of coupled transfers of heat and mass during a superficial drying of mint (mentha sp) for the sake of determining the distributions of the temperature and humidity of air in the interface and in the mint leaves.

Nomenclature

Latin letters

a_q : Coefficient of thermal diffusion **[m² / s]**
a_m : Coefficient of massif diffusion **[m² / s]**
HR : relative humidity **[%]**
L : Length characteristic of mint leaves **[m]**
L_V : Latent heat of evaporation of free water **[J / kg]**
P : Pressure **[Pa]**
T : Température **[°C]**
u, v : Axial component and radial of velocity **[m / s]**
W : Humidity **[kg of water / kg dry matter]**

Greek letters

ρ : Volumic mass **[kg / m^3]**
λ : Thermal conductivity **[W / m °C]**
ν : Cinematic viscosity **[m² / s]**
τ : Adimensional time

Inferior indication

0 : Initial
1 : Air in interface
2 : Product (mint leaves)
∞ : Drying air
cr : Critical

2. Presentation of the model and reference

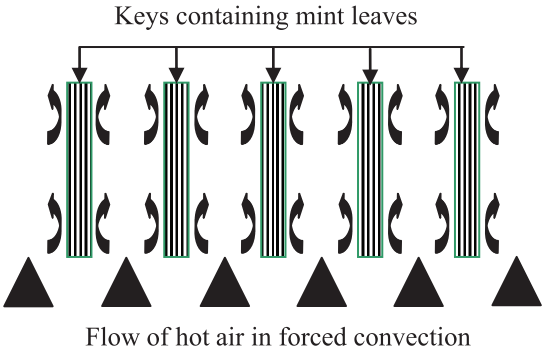

Fig. 1. Representation of the keys and the flow of hot air inside the enclosure of drying.

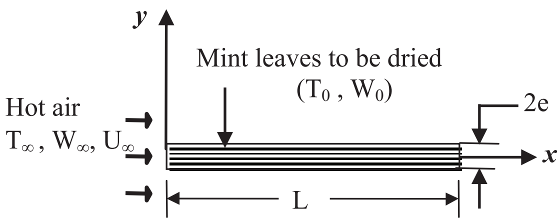

Fig. 2. Schematic Presentation of the system and referential

3. Simplified hypotheses

Due to the complexity of the studied problem, simplified hypotheses are suggested at the level of the two mediums **[6]**, **[7]**, **[8]** and **[9]**.

On the level of the air of drying, the physical properties of the fluid are independent of the temperature and time. The air flow is laminar, two-dimensional and transitory. The heat brought by evaporation to the surface of the mint leaves is negligible.

On the level of the product, the mint leaves are indeformable and sufficiently wet and long so that the tangential variations of temperature and moisture can be neglected. The evaporation of the water of the leaves is superficial.

4. Mathematical Formulation of the problem

The preceding simplified hypothesis, lead us to write the following equations:

4.1. In drying air

$$\frac{\partial u_1}{\partial x}+\frac{\partial v_1}{\partial y}=0 \tag{1}$$

$$\frac{\partial u_1}{\partial t}+u_1\frac{\partial u_1}{\partial x}+v_1\frac{\partial u_1}{\partial y}=-\frac{1}{\rho_1}\frac{\partial p}{\partial x}+\nu\left(\frac{\partial^2 u_1}{\partial x^2}+\frac{\partial^2 u_1}{\partial y^2}\right) \tag{2}$$

$$\frac{\partial v_1}{\partial t}+u_1\frac{\partial v_1}{\partial x}+v_1\frac{\partial v_1}{\partial y}=-\frac{1}{\rho_1}\frac{\partial p}{\partial y}+\nu\left(\frac{\partial^2 v_1}{\partial x^2}+\frac{\partial^2 v_1}{\partial y^2}\right) \tag{3}$$

$$\frac{\partial T_1}{\partial t}+u_1\frac{\partial T_1}{\partial x}+v_1\frac{\partial T_1}{\partial y}=a_{q1}\left(\frac{\partial^2 T_1}{\partial x^2}+\frac{\partial^2 T_1}{\partial y^2}\right) \tag{4}$$

$$\frac{\partial W_1}{\partial t}+u_1\frac{\partial W_1}{\partial x}+v_1\frac{\partial W_1}{\partial y}=a_{m1}\left(\frac{\partial^2 W_1}{\partial x^2}+\frac{\partial^2 W_1}{\partial y^2}\right) \tag{5}$$

The initials and limits conditions are written as:

$$\begin{aligned}
&\text{For } t=0\ \forall x \text{ and } \forall y \quad ; \quad T_1=T_\infty\ ,\ W_1=W_\infty\\
&\text{For } t\succ 0 \text{ at } x=0 \text{ and } y=e\ ,\ u_1=v_1=0\ ,\ T_1=T_\infty\ ,\ W_1=W_\infty\\
&\qquad \text{at } x=0 \text{ and } y\succ e\ ,\ u_1=U_\infty\ ,\ v_1=0\ ,\ T_1=T_\infty\ ,\ W_1=W_\infty\\
&\qquad \text{at } x=L \text{ and } y\succ e\ ,\ \frac{\partial T_1}{\partial x}=\frac{\partial W_1}{\partial x}=0\\
&\qquad \text{at } y=e \text{ and } x\neq 0\ ,\ u_1=v_1=0\\
&\qquad \text{at } y\to\infty \text{ and } \forall x\ ,\ u_1\to U_\infty\ ,\ v_1\to 0\ ,\ T_1\to T_\infty\ ,\ W_1\to W_\infty
\end{aligned} \tag{6}$$

4.2. In the mint leaves

$$\frac{\partial T_2}{\partial t}=a_{q2}\left(\frac{\partial^2 T_2}{\partial x^2}+\frac{\partial^2 T_2}{\partial y^2}\right) \tag{7}$$

$$\frac{\partial W_2}{\partial t}=a_{m2}\left(\frac{\partial^2 W_2}{\partial x^2}+\frac{\partial^2 W_2}{\partial y^2}\right) \tag{8}$$

The initials and limits conditions as:

For $t=0\ \forall x$ and $\forall y$; $T_2=T_0\ ,\ W_2=W_0$

For $t\succ 0$ at $x=0$ and $y\prec e\ ,\ T_2=T_\infty\ ,\ W_2=W_{cr}$

$$\text{at } y = e \text{ and } \forall x,\ \frac{\partial T_2}{\partial y} = \frac{\partial W_2}{\partial y} = 0 \tag{9}$$

$$\text{at } x = L \text{ and } y \prec e,\ \frac{\partial T_2}{\partial x} = \frac{\partial W_2}{\partial x} = 0$$

According to the **Henderson's [10]** we have:

$$W_{cr}(T_\infty, HR) = \left[\frac{-Ln(1-HR)}{k(1.8T_\infty + 492)}\right]^{\frac{1}{n}} \tag{10}$$

The constants *k* and *n* depend on the temperature and characteristics of the mint.

4.3. Equations of de transfers in the interface air-mint leaves

The heat and mass balance sheet in the interface air-mint leaves are written as follows:

$$\lambda_2\left[\frac{\partial T_2}{\partial y}\right]_s = \lambda_1\left[\frac{\partial T_1}{\partial y}\right]_s + L_v \rho_1 a_{m1}\left[\frac{\partial W_1}{\partial y}\right]_s \tag{11}$$

$$\rho_2 a_{m2}\left[\frac{\partial W_2}{\partial y}\right]_s = \rho_1 a_{m1}\left[\frac{\partial W_1}{\partial y}\right]_s \tag{12}$$

On the interface of air-mint leaves, the humidity W_1 must correspond to the conditions of saturation of the air because it is on this surface that evaporation takes place. These conditions are précised by the classical formula relating the absolute humidity to the pressure of latent vapor P_{vs} **[8]**, **[11]**, and **[12]**.

5. Adimensionalization of equations of transfer

In order to generalize the problem, we have introduced in the equations of transfer adimentional variables below.
In the equations (1-5) of air, we have introduced the fallowing variables:

$$X^* = \frac{x}{L},\ Y^* = \frac{y}{L},\ U^* = \frac{u_1}{U_\infty},\ V^* = \frac{v_1}{U_\infty},\ T_1^* = \frac{T_1}{T_\infty},\ W_1^* = \frac{W_1}{W_\infty},\ P^* = \frac{p}{\rho_1 U_\infty^2},\ \tau = \frac{u_\infty t}{L}$$

Similar to the equations (7-8) of mint leaves the adimentional variables are:

$$X^* = \frac{x}{L},\ Z^* = \frac{y}{L},\ e^* = \frac{e}{L},\ T_2^* = \frac{T_2}{T_\infty},\ W_2^* = \frac{W_2}{W_0},\ \tau = \frac{a_{q2}}{L^2}t$$

The adimentional equations obtained may be written under the fallowing general formula:

$$\frac{\partial \phi}{\partial \tau} + div(C_i \phi) = \Gamma_\phi div(grad\phi) + S_\phi \tag{13}$$

ϕ : Dependent variable that can present speed, temperature and humidity,
Γ_ϕ : Diffusion coefficient,
S_ϕ : source term.
The variables ϕ, Γ_ϕ and S_ϕ are given in the fallowing table1.

Table1. Coefficients of equation (13)

Equation of	ϕ	Γ_ϕ	S_ϕ
Continuity	1	0	0
movement fallowing the axe X	U^*	$1/Re$	0
movement fallowing the axe Y	V^*	$1/Re$	0
Energy	T_1^*	$1/Pe$	0
Humidity	W_1^*	$1/Sc$	0
heat transfer	T_2^*	1	0
mass transfer	W_2^*	Lu	0

6. Results and discussions

Test of convergence and stability of the system enabled us to adopt a grid of (25x22) for the air of drying and a grid of (25x43) for the mint leaves.

The equations of transfers in the two mediums are resolved by a numerical program based on a **SIMPLER** lgorithm developed by Patankar [**13**].

The examination of the profiles of temperature T_1 of the air in the interface shows that this size decreases with x for all the values of y. As illustrated in figure 3 for which the drying time is taken equal to 12 hours.

During all the hours of drying and for a value of Y^* equal to 1.15, the temperature T_1 of the air remains always decreasing with x-coordinate (figure 4). The evolution of the profiles of temperature of the air in the interface shows also that the latter decrease when drying time increases (figure 4).

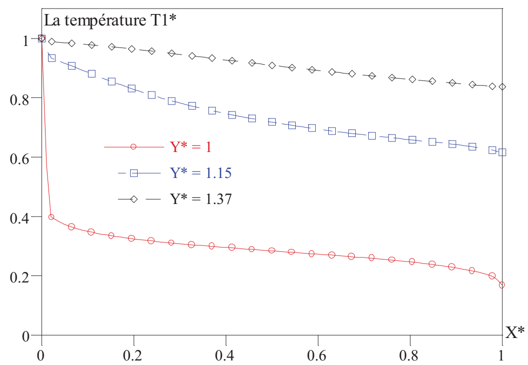

Fig. 3. Distribution of the temperature of the air in the interface layer in function to the X^* for various values of Y^*

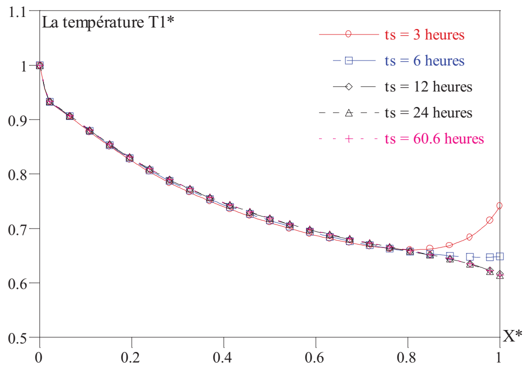

Fig. 4. Distribution of the temperature of the air in the interface layer in function to the X^* for various values of drying time.

On figure 5, we note that for the low values of x, humidity W_1 of the air in the interface layer increases bluntly while Y^* is equal to 1. This is explained by the fact that rears the attack surface, horizontal and vertical components of the air velocity are negligible and that the diffusion dominates according to the convection. On the other hand the convection becomes increasingly dominant when one moves away from the attack surface. The diffusion, as for it, becomes quasi absent for these points.

The boundary conditions on the surface of the mint leaves have a strong influence on humidity W_1 of the air in the interface layer above all low values of x. This influence results in an abrupt increasing of this humidity (figure 6). Beyond the low values of x humidity increases then decreases.
We observe also on this figure a clear increasing of the humidity of the air when drying time is over.

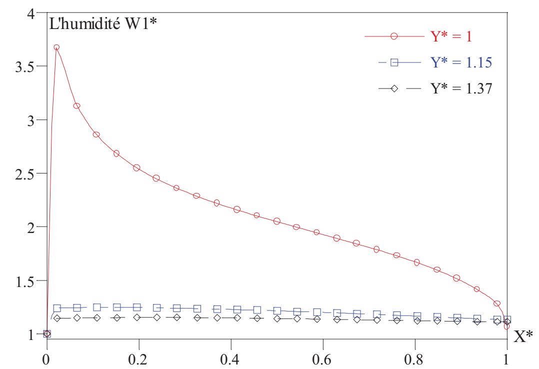

Fig. 5. Distribution of the humidity of the air in the interface layer in function to the X^* for various values of Y^*.

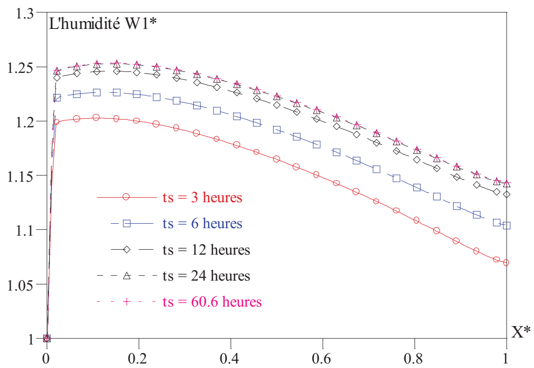

Fig. 6. Distribution of the humidity of the air in the interface layer in function to the X^* for various values of drying time.

Figure 7 show a decreasing of the temperature T_2 of the mint leaves in function to the x-coordinate and an increase in this size with ordinate z.

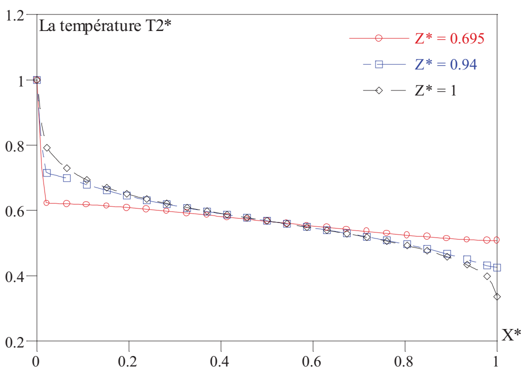

Fig. 7. Distribution of the temperature in the mint leaves in function to the X^* for various values of Z^* at the end of 12 hours

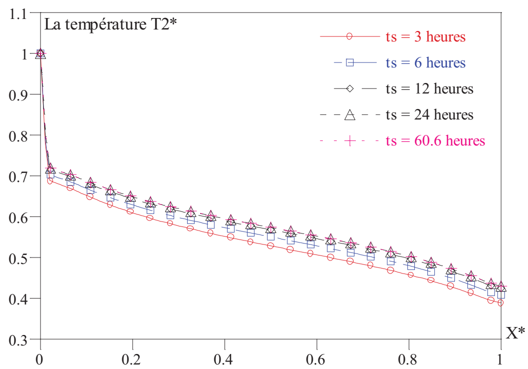

Fig. 8. Distribution of the temperature in the mint leaves in function to the X^* for various values of drying time and for $Z^* = 0.94$.

On figure 8, we found out that the temperature of the product T2 increases through the time of drying. When we move far from the surface of the mint leaves, humidity W_2 acquires increasingly high values (figure 9).

For a value of z chosen equal to 0.94 (near the surface), humidity W_2 in the mint leaves decreases when drying time increases until obtaining an final value that corresponds to the critical state (for a final drying time equal to 60,6 hours) which corresponds at the end of the operation of drying (figure 10).

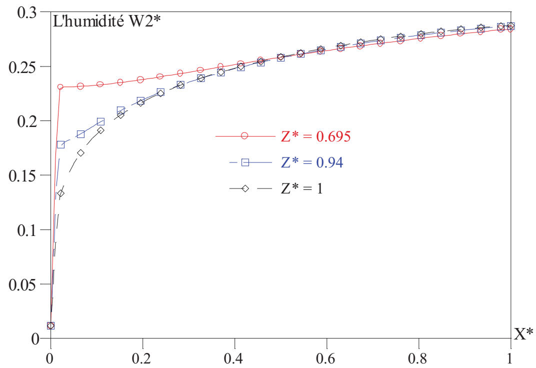

Fig. 9. Distribution of humidity in the mint leaves in function to the X^* for various values of Z^*

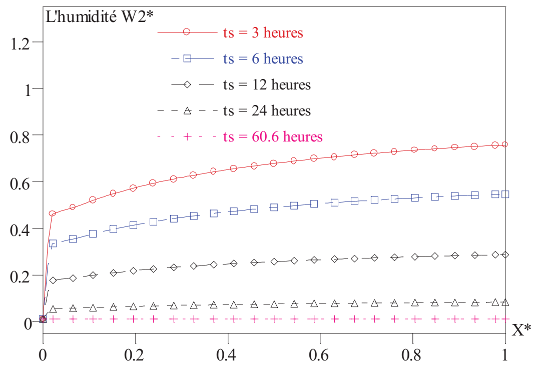

Fig. 10. Distribution of humidity in the mint leaves in function to the X^* for various values of drying time.

7. Conclusion

The coupling of the equations of the air in the layer of interface with those which describe the transfer of heat and mass in the porous mediums permits to modelize the phenomena of the operation of drying without having recourses to the global coefficient of transfers of heat and mass between the air and the product.
This modelization permits to understand better the drying process since it takes into consideration the effects of diffusion and convection in the interface.
The method used in the modelization is the one the best known of finished volumes. This modelization goes back to the calculation code developed by Patankar and based on the **algorithm** of Simpler, who in his initial version treats only phenomena where one medium is included. For this, we have made a numerical development at the level of calculating code in order to solve all the equations of transfer that describe the various phenomena taking part during the drying characterized by the presence of two different mediums.
In the case of mint, time of drying is of the order of 60 hours for a velocity, humidity and a temperature of the air which corresponds respectively to 1m/s, 0.01kg of water/kg of dry air and 45°C.

Bibliography

[1] M. Daguenet, Le séchage solaire théorie et pratique, UNESCO, Paris, 1985.
[2] S. Whitaker, Simultaneous Heat , Mass, and Momuntum Transfer in Porous Media : A theory of draying, in Advances in Heat Transfer, vol. 13, academic, New York, pp 119-203, 1977.
[3] S. Whitaker, Heat and Mass transfer in granular porous media, in Advances in draying, vol. 1, Ed A. S Mujumdar, Hemisphere Publ. Corp. Washington pp 23-59.

[4] A.V. Luikov, Heat and mass transfer in capillary porous bodies, Advance in heat transfer, vol 1, New York, 1964.

[5] J. M. Hernandez, Séchage du chaîne: caractérisation, procédés convectif et sous vide, Thèse de Doctorat, Université de Bordeaux, 1991.

[6] B. TOUATI, Modélisation numérique des transferts couplés de chaleur et de masse lors du séchage des feuilles de menthe (mentha sp), mémoire de Magister, centre universitaire de Béchar, 2001.

[7] A. Bennis, Transferts de chaleur et de masse lors du séchage du liège par convection forcée, Thèse de Doctorat, Université de Marrakech, 1997.

[8] Hamed Amir, Séchage d'un matériau poreux humide par convection forcée d'air chaud : Couplage entre les équations de transfert dans le matériau et celles de la couche limite « Application au séchage solaire du bois », Thèse de Doctorat, Université de Perpignan, 1985.

[9] A. Touhami, Etude de séchage d'un cylindre annulaire poreux humide sous l'action d'un courant d'air forcé dans le conduit central: Couplage entre les équations de LUIKOV et celles de la couche limite, Thèse de Doctorat, Université de Perpignan, 1990.

[10] M. Kouhila, A. Belghith, M. Daguenet, Approche expérimentale des courbes de sorption de la menthe en vue d'un séchage par énergie solaire, pp 61-68, Rev. Energ. Ren., vol N°2, 1999.

[11] H. Amir, G. Le Pelec et M. Dagueunet, Séchage superficiel d'un matériau poreux humide par convection forcée d'air chaud : Couplage entre les équations de transfert dans le matériau et celles de la couche limite, Int. J. Heat Mass Transfer, Vol. 30, N°6, pp 1149-1158, 1987.

[12] J. F. Sacadura, Initiation au transfert thermique, CAST. INSA, Lyon, 1978.

[13] Suhas V. Patankar, Numerical heat transfer and fluid flow, édition McGRAW-HILL BOOK COMPANY, 1980.